RESEARCH PROGRAM

Dmitry B. Rokhlin
dbrohlin@sfedu.ru
I.I. Vorovich Institute of Mathematics, Mechanics and Computer Sciences of Southern Federal University
Regional Scientific and Educational Mathematical Center of Southern Federal University

1 RESEARCH INTERESTS

My research interests are always changing. In general they concern decision making under uncertainty, stochastic methods, optimization, mathematical finance, machine learning. My latest works deal with applications of online learning methods to portfolio optimization, resource allocation and incentive mechanisms.

Some previous results concern

- learning theory: asymptotic sequential Rademacher complexity of a finite function class, Q-learning in a stochastic Stackelberg game;
- probability theory: central limit theorem under model uncertainty;
- optimal control: optimal harvesting, optimal production and pricing strategies, applications of the stochastic Perron method to exit time and phase constraints problems;
- financial mathematics: no-arbitrage criteria for market models with portfolios constraints, with transaction costs, for large market models; lower bounds for martingale measure densities in discrete time models; study of a shadow price process in utility maximization problems under transaction costs;
- stochastic analysis: martingale selection theorem (discrete time), a theorem on the existence of an equivalent supermartingale density for a fork-convex family of stochastic processes;
- functional analysis: versions of the Kreps-Yan theorem on the separability of cones in spaces of measurable functions;
- fluid mechanics: impact of a planar body floating over a fluid of small depth; analysis of the spectrum of the Laplace tidal equations on a compact surface with boundary.

2 PROJECT DESCRIPTION

The project will be devoted to the applications of the method of signatures, originating in the rough paths theory invented in 1990s by Terry Lyons. This theory led to remarkable achievements in stochastic analysis. More recently it was realized that the signature method provides very useful description of data streams. Signatures, defined as iterated integrals, can be used as features for machine learning methods. Many researchers now are very optimistic about the capabilities of this approach, and even regard it as a new era in data analysis, although the signature methods need not necessary beat other approaches in concrete problems. This method of modelling provides unified and fully non-parametric approach to various dynamic phenomena. There are several practical problems which were already successfully studied with the signature method, e.g., extracting information from financial data streams, handwriting recognition, human action recognition, optimal execution of financial transactions, medical diagnoses, etc. Already existing software like the Python package `iisignature` implements convenient signature computation for given data streams. Besides classical machine learning problems, such as classification (of time series), the signature method has great potential for applications in such areas as optimal control and dynamic games.

Possible research problems:

- *Change point detection using the signature method.* The problem is to monitor the path, which is a realization of a known stochastic process, and to detect the time moment (if any), when it switches

to a realization of another stochastic process. For instance, when the drift or the volatility of the diffusion process changes.

- *Dynamic portfolio optimization using the price path signatures as features*. The portfolio weights can be represented as images of the price path signatures under a mapping, represented by a neural network. There is a lot of results concerning online learning algorithms for portfolio selection. It would be interesting to develop a competitive signature-based algorithm.
- *Understanding of the signature-based reservoir computing*. Recently Josef Teichmann with co-authors proposed a reservoir method for learning a multidimensional stochastic system, represented by a stochastic differential equation with unknown vector field. The system dynamics is learned by the linear regression of the observed realization on the dynamical features, collected from the problem-independent reservoir. The problem is to understand this intriguing approach, an to extend its application area.
- *Experimental study of the generalised signature method for time series classification*. This method, recently developed J. Morrill and co–authors including T. Lyons, consists in supplementing the signature method by several data processing procedures: augmentations, windows, transforms and rescalings. The authors of the method claim that they were able to produce a canonical signature pipeline, which is comparable to current state-of-the-art classifiers. It is possible that this approach can be applied also to the change point detection.

3 Prerequisites

- Undergraduate level linear algebra, mathematical analysis, probability, programming (python).
- The ability and the desire to study new theories, to read contemporary papers, to understand the existing software and to write your own code.

4 Working mode

The main part of the work should be done by the student independently. The guidance will be provided. For online meetings I prefer MsTeams.